

ACTIVE GALACTIC NUCLEI

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OVERVIEW

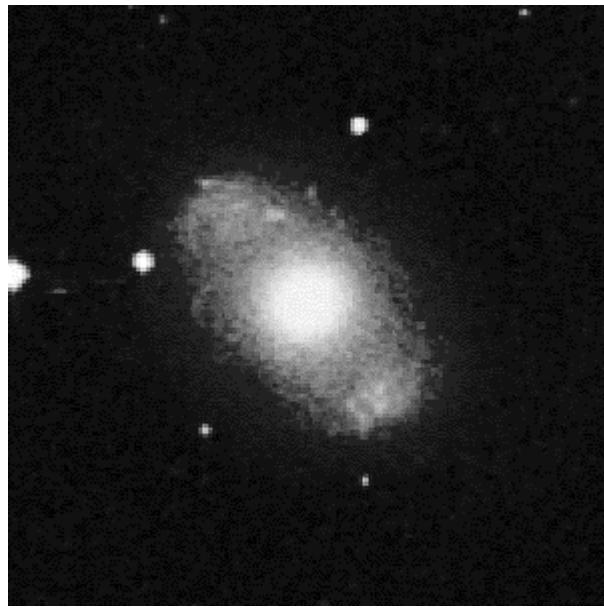
PART 1

PARTS 2+3

- What are AGN?
- Why are they interesting?
- What are the observables?
- Is there a unified model for the various types?
 - 2. *How can we derive the physics of AGN from the observations*
 - 3. *What is the evidence for a black hole and accretion disk*

ACTIVE GALAXIES

ACTIVE: NGC 4151



LINER: NGC 3031



WHAT ARE AGN?

- IN GENERAL
 - Emit orders of magnitude more energy than normal galaxies, concentrated in a very small, nuclear region
- SEYFERT GALAXIES
 - Discovered in 1943 by Carl Seyfert
 - Peculiar, broad, high ionization emission lines in the optical
 - Nuclear emission exceeds normal galaxy by 1-5 orders of magnitude
 - Make up about 1% of all galaxies
- QUASARS
 - Discovered in 1963
 - Point like (“quasi-stellar”) on photographic plates
 - Emit 5-8 orders of magnitude more than normal galaxies
- LINERS/LLAGN
 - About 10% of all galaxies show some kind of evidence for activity (point-like nuclei, strong emission lines, etc.) though not necessarily dominant

THE MODEL

- Shortly after the discovery of quasars it was suggested that AGN were powered by accretion onto a supermassive black hole.
- But what evidence is there for this hypothesis?

PROGRESSION OF KNOWLEDGE?

- Compile observables
 - Classify and separate into subclasses
 - Make empirical model for subclasses
 - Make physical model
 - **Reunify!**
- The best models will have a minimum of parameters, but these will include:
- Black Hole Mass
 - Black Hole Spin
 - Accretion Rate
 - Viewing angle
 - Others...

WHY ARE AGN IMPORTANT?

- AGN are the most luminous steady sources of radiation in the universe, and the most compact
- They allow us to study matter very close to black holes and the black holes themselves
- They are observed out to enormous distances (redshifts) and therefore can be used as cosmological probes in several ways
- Black holes are present in all galaxies, and the formation and evolution of the black hole is related to the formation of the galaxy

X-RAY COMPACTNESS LEAGUE TABLE

	L_x erg s-1	R(cm)	L_x/L	R(AU)	L/R
AGN	10^{40} - 10^{47}	10^{14} - 10^{16}	10^7 - 10^{14}	2-200	10^4 - 10^{13}
Galaxy Clusters	10^{43} - 10^{46}	10^{24} - 10^{26}	10^{10} - 10^{13}	10^{10} - 10^{12}	10^{-2} - 10^3
Normal Galaxies	10^{38} - 10^{40}	10^{22} - 10^{23}	10^5 - 10^7	10^9 - 10^{10}	10^{-5} - 10^{-2}
Supernovae	10^{35} - 10^{37}	10^{17} - 10^{19}	10 - 10^4	10^4 - 10^6	10^{-5} - 1
Stars, X-ray binaries	10^{30} - 10^{37}	10^6 - 10^{11}	10^{-3} - 10^4	10^{-7} - 10^{-2}	10^{-1} - 10^{11}

FLUX, LUMINOSITY AND DISTANCE

- Cosmology makes “distance” a different concept
- The directly measurable quantity is Cosmological redshift (z). This is measured by identifying known emission lines in the optical/UV and computing their energy shift. $1+z = E_{\text{rest}}/E_{\text{observed}}$
- Need a cosmological model to turn this into a distance
- Define “Luminosity Distance”, d_L , such that $F=L/4\pi d_L^2$
- d_L depends on the Hubble constant H_0 and cosmological deceleration parameter q_0 , but for small distances $d_L=cz/H_0$. We will use $H_0=50 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and $q_0=0$
- The closest “classical” AGN is NGC 4151 ($z=0.0033$; $\sim 20 \text{ Mpc}$)
- The most distant AGN is SDSSP J104433.04-012502.2 at $z=5.8$

Redshift Distribution

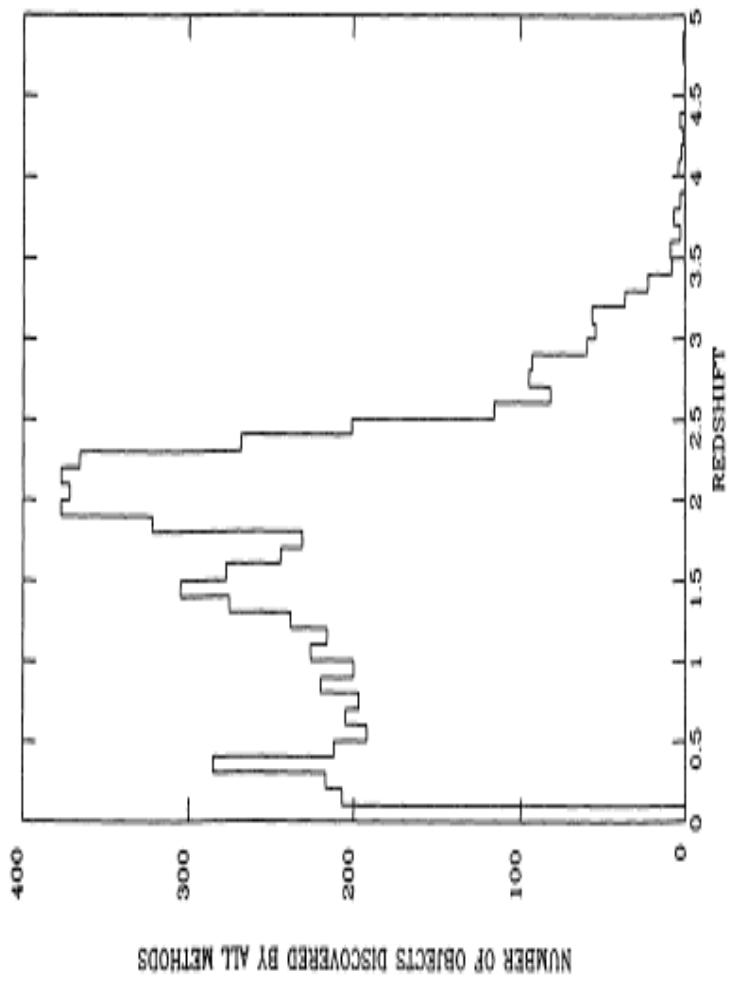


FIG. 3.—Histogram showing the emission redshift distribution for all of the QSOs in Table 1.

Hewitt & Burbidge (1993)

WHAT ARE THE OBSERVABLES?

OBSERVABLE:	INFORMATION ON:
Continuum Shape (Spectrum)	Physics of emission mechanism Temperature of emitting regions Dust and gas absorption
Continuum Variability	Emission mechanism Structure size and geometry of emission regions
Emission line strength	Temperature, density physical state and element abundances of matter in AGN on all scales
Emission line shape/profile	Velocity structure of matter, central mass, Doppler and/or gravitational energy shifts, black hole spin?
Emission line variability	Size, geometry and structure of matter distribution. Black hole mass.
Absorption	Physical state (ionization, column density) of matter in the line of sight; geometry

MAIN FEATURES OF AGN CONTINUUM SPECTRAL ENERGY DISTRIBUTIONS

- **FLAT** – approximately equal luminosity emitted per decade of frequency from infrared to gamma rays
- **RADIO** - (loud/quiet) distribution of radio power is bimodal ($\sim 10\%$ RL)
- **INFRARED** – strong peak due to dust emission. More dust, more emission.
- **OPTICAL** – complex continuum plus emission line. Stellar emission can contaminate.
- **BIG BLUE BUMP** - UV/soft X-ray excess above extrapolated continuum. Relative strength varies. Though to be thermal emission from *accretion disk*.
- **EXTREME ULTRAVIOLET (EUV)** - extinguished by absorption in the line-of-sight
- **X-RAYS** - power law continuum affected by reflection features; rolls over at ~ 100 keV in radio quiet AGN
- **GAMMA-RAYS** – Most RQ AGN not detected in γ -rays, Some RL AGN detected as high as TeV range

Schematic SEDs

- The spectrum can be specified in terms of flux per unit energy (or frequency): F_E in $\text{erg cm}^{-2} \text{s}^{-1} \text{keV}^{-1}$ or F_ν in $\text{erg cm}^{-2} \text{s}^{-1} \text{Hz}^{-1}$, but more often we multiply by E or n to get EF_E or vF_n , which have equal flux per unit energy
- Peaks and troughs in the vF_n plot show local maxima and minima of emitted energy. The highest point shows where most of the power is emitted
- A flat vF_n spectrum means approximately equal power is emitted per unit frequency
- BOLOMETRIC flux is that integrated over the whole spectrum

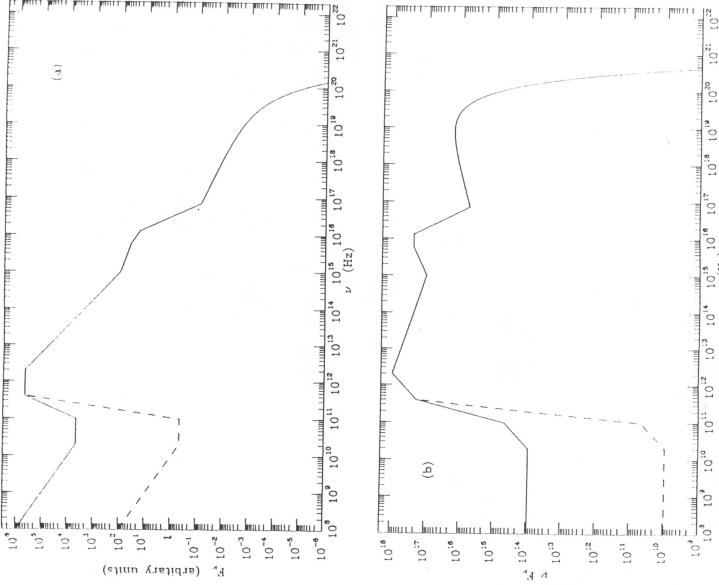


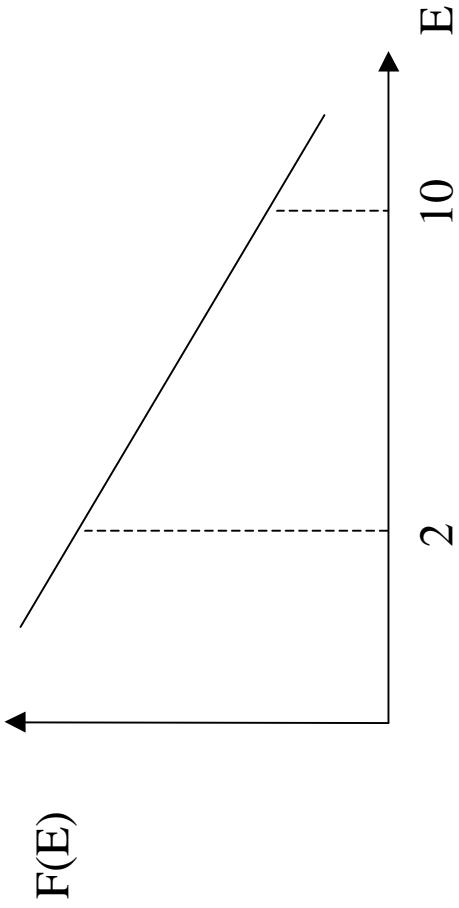
Figure 4.2 (a) Flux per unit frequency for the ‘mean’ AGN continuum (see §4.1.7 for details). The X-ray photon spectral index is 1.7 and the γ -ray cut-off is 100 keV. (b) As (a) with the spectrum plotted in vF_n space (equal areas corresponding to equal luminosities). The dotted curves correspond to a ‘radio quiet’ version (see text).

X-RAYS FROM AGN

- Emission is ubiquitous
- Non-thermal, power-law form
- Probably from inverse Compton scattering
- X-rays suffer absorption and scattering when passing through intervening medium

X-RAY SPECTRUM: EXAMPLE

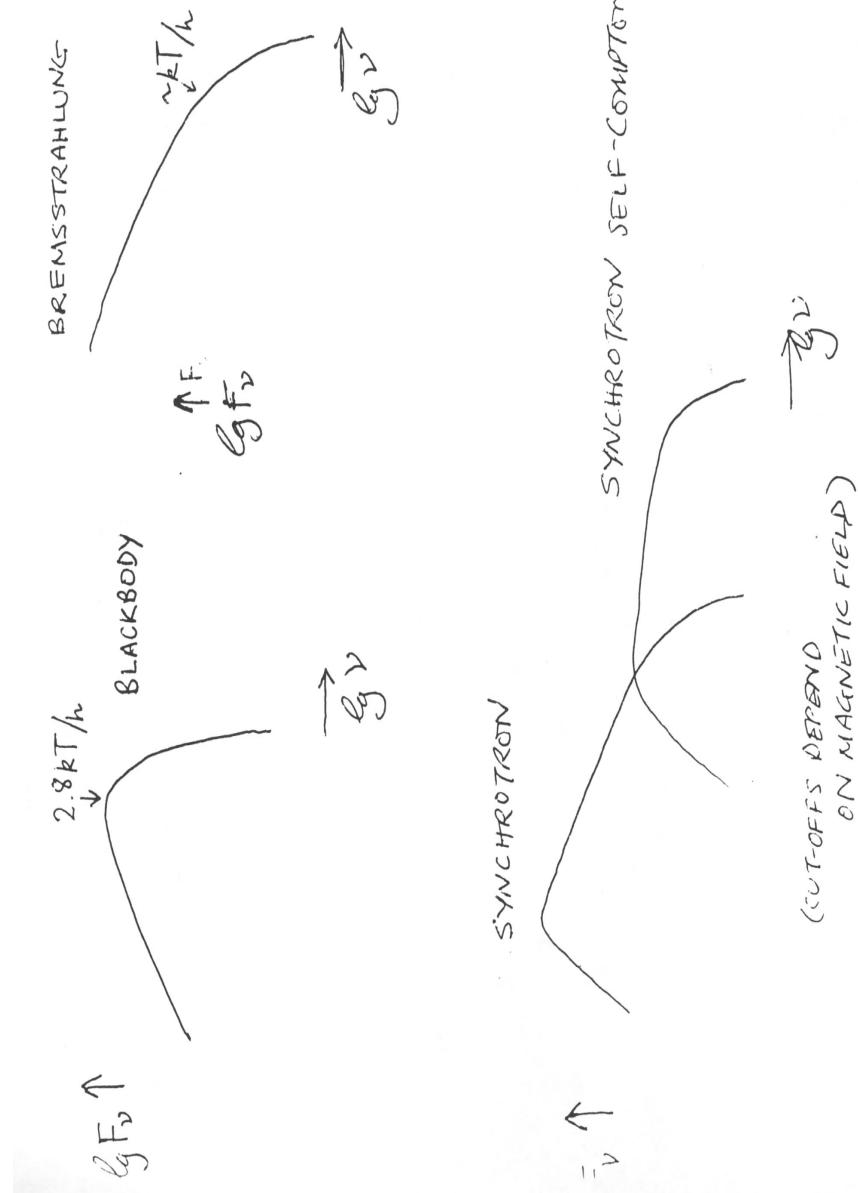
- Spectrum $F(E) = AE^{-\alpha} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ keV}^{-1}$
- $\alpha = 0.7; A = 1.6 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ keV}^{-1}$
- α known as spectral index. What does A represent?
- What is the 2-10 keV Flux?



EMISSION MECHANISMS

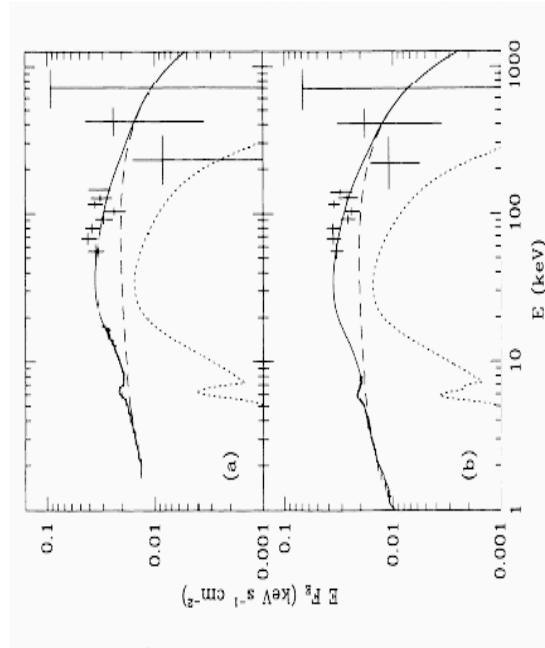
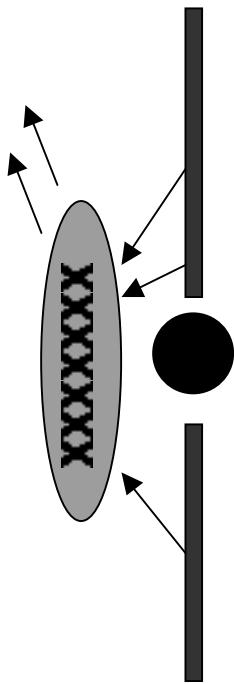
- THERMAL (emission by electrons with thermal/Maxwellian velocity distribution)
 - Optically thick (black body)
 - Optically thin (bremsstrahlung or free-free)
- NON-THERMAL (electrons not in thermal equilibrium)
 - Synchrotron
 - Synchrotron self-Compton

Schematic Spectra



INVERSE COMPTON SCATTERING IN AGN

- Thermal Comptonization is a kind of hybrid thermal/non-thermal process. The electron distribution is thermal, but the spectrum is non-thermal (power law) produced by inverse Compton scattering of low energy photons off the hotter electrons.

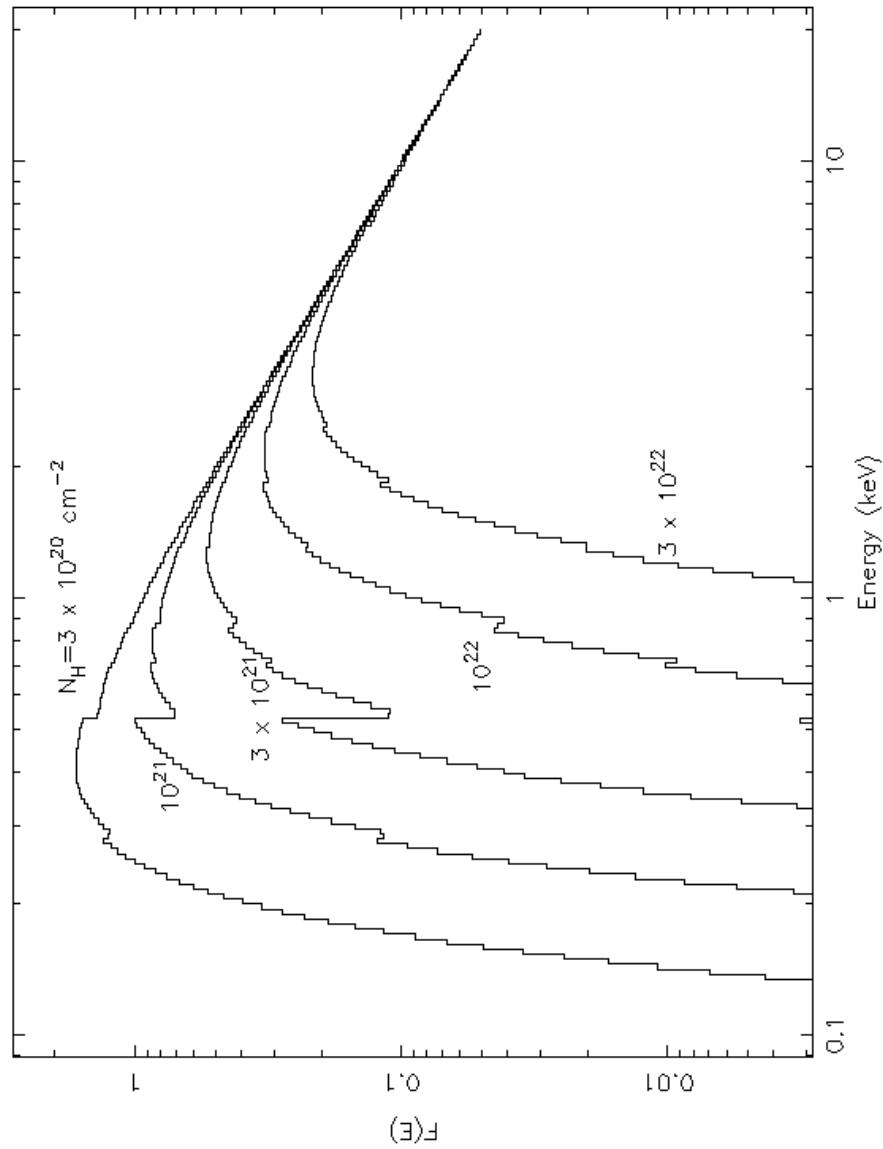


X-RAY ABSORPTION

- Photo-electric absorption by bound electrons in atoms (there is also Compton scattering by bound electrons)
- Characterized by:
 - NH column density of absorbing material, related to density and thickness R by $N_H = nR$; units are cm^{-2}
 - $\sigma(E)$ photo-electric absorption cross section units of cm^2
 - $\tau = N_H \sigma(E)$ is called the optical depth (dimensionless)
- Cross section has discontinuities- absorption edges due to particular elements – at certain energies. Immediately above these energies the form is approximated by $\sigma(E) \propto E^{-3}$
- Typical column densities of ISM in our Galaxy are $10^{19}\text{-}10^{21} \text{ cm}^{-2}$
- Column densities in AGN depend on class but can be $> 10^{24} \text{ cm}^{-2}$

X-RAY ABSORPTION

Cold, neutral absorption by matter with “cosmic” abundance.
 $F(E) = E^{-1} \exp(-\sigma(E)N_H)$



OPTICAL EMISSION LINES

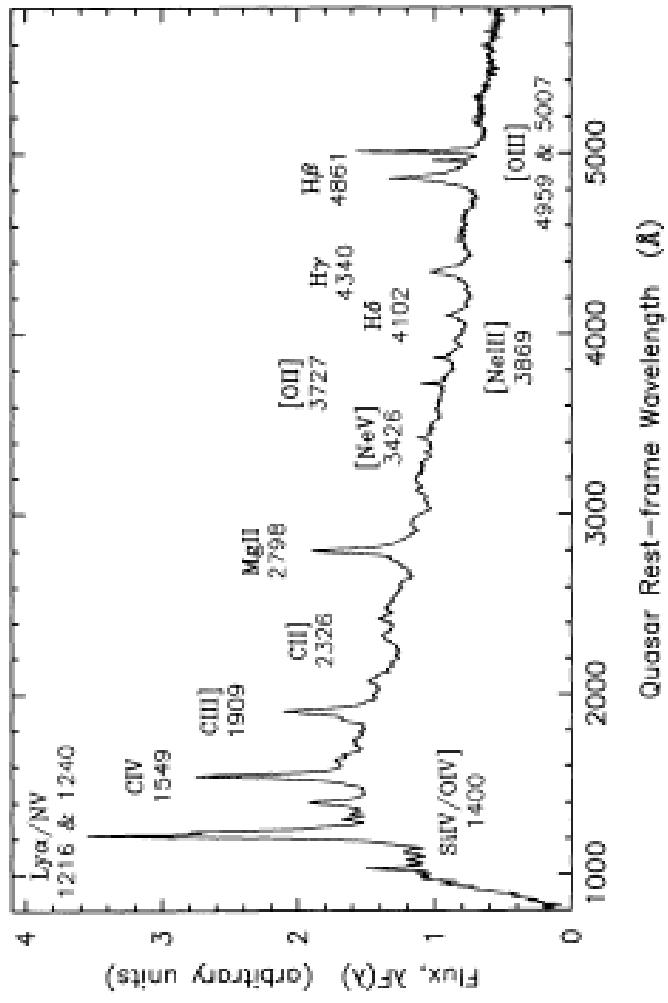
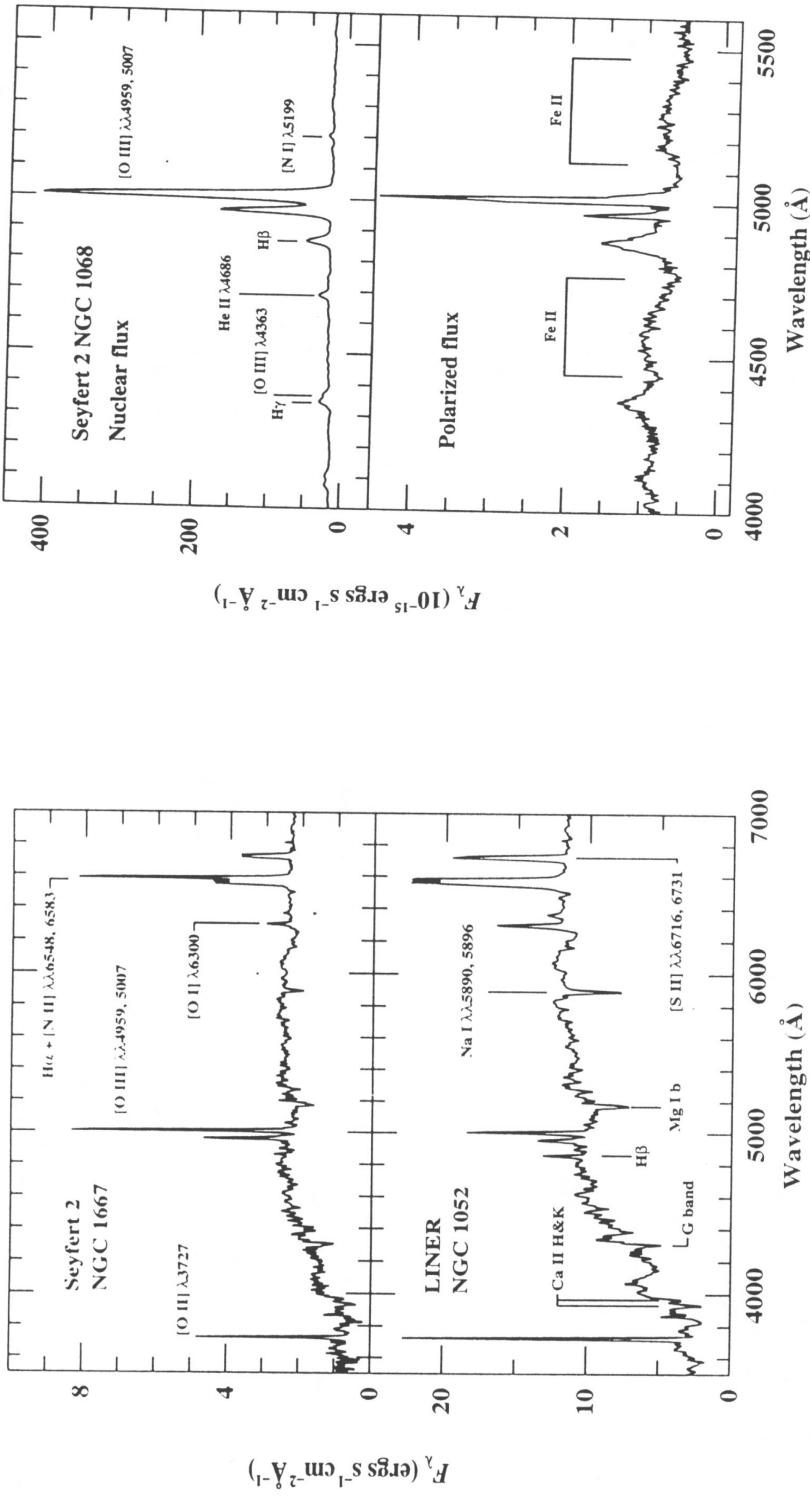


FIG. 2.—Composite spectrum plotted as $\lambda F(\lambda)$ vs. rest-frame wavelength with the principal emission features identified. The flux scale is in arbitrary units.

Francis et al. (1991) composite spectrum of 700 QSOs

NARROW LINE OBJECTS



DOPPLER BROADENING OF LINES

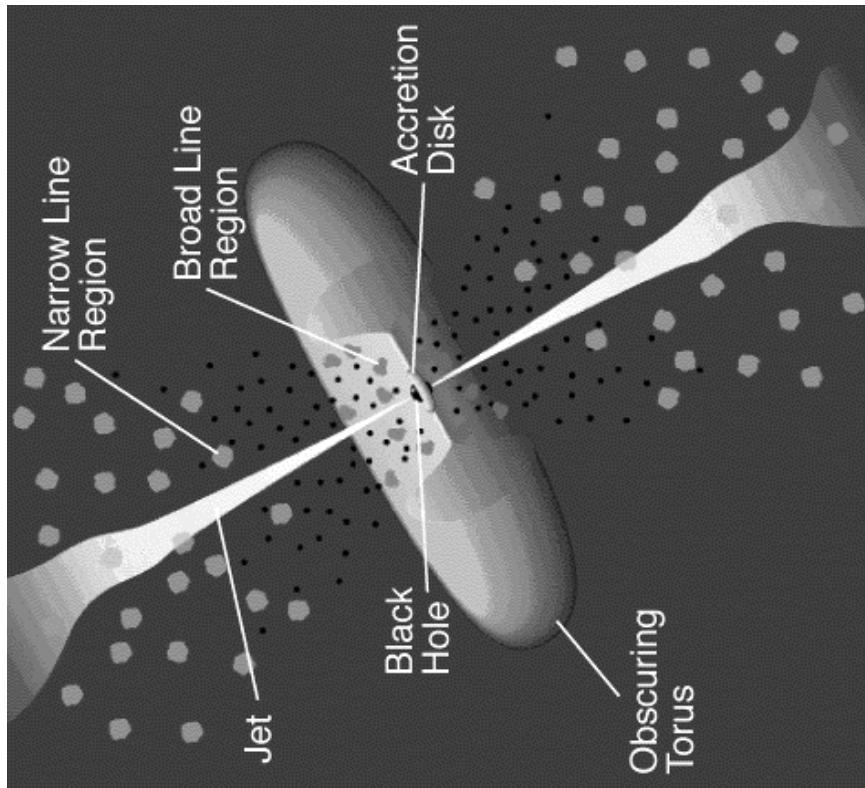
- Doppler effect causes lines to be broadened
 - Atom emits line at single energy E_0
 - Receding matter gives redshift (lower energy); approaching matter gives blueshift (higher)
 - Lots of atoms gives broad profile to line
- Line widths are often expressed as FWHM (Full Width at Half Maximum) and FWZI (Full Width at Zero Intensity) as well as gaussian σ and generally as an equivalent velocity
- Approximately ($v < c$) $v/c \sim \Delta E/E$
- Where relativistic velocities exist,

$$E_{\text{obs}}/E_0 = \sqrt{(1-\beta)/(1+\beta)} \quad \text{where } \beta = v/c$$

What do NLR and BLR line widths imply about the distance?

AGN UNIFIED MODEL

- Differences in AGN are due to *orientation*
- Broad lines arise from closer than narrow
- Broad lines obscured by dusty “torus”
- Narrow lines visible, and broad lines seen in scattered light
- Confirmed as high X-ray absorption in “type 2” (narrow line) AGN



UNIFIED MODEL

- Seyfert 1 observed
“face on” along axis of torus
- Seyfert 2 observed
edge on through torus
so central source not easily seen

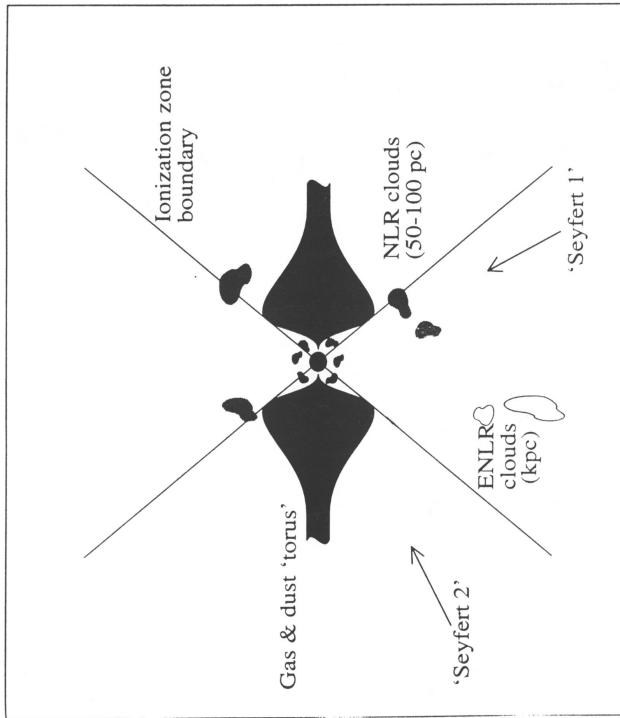
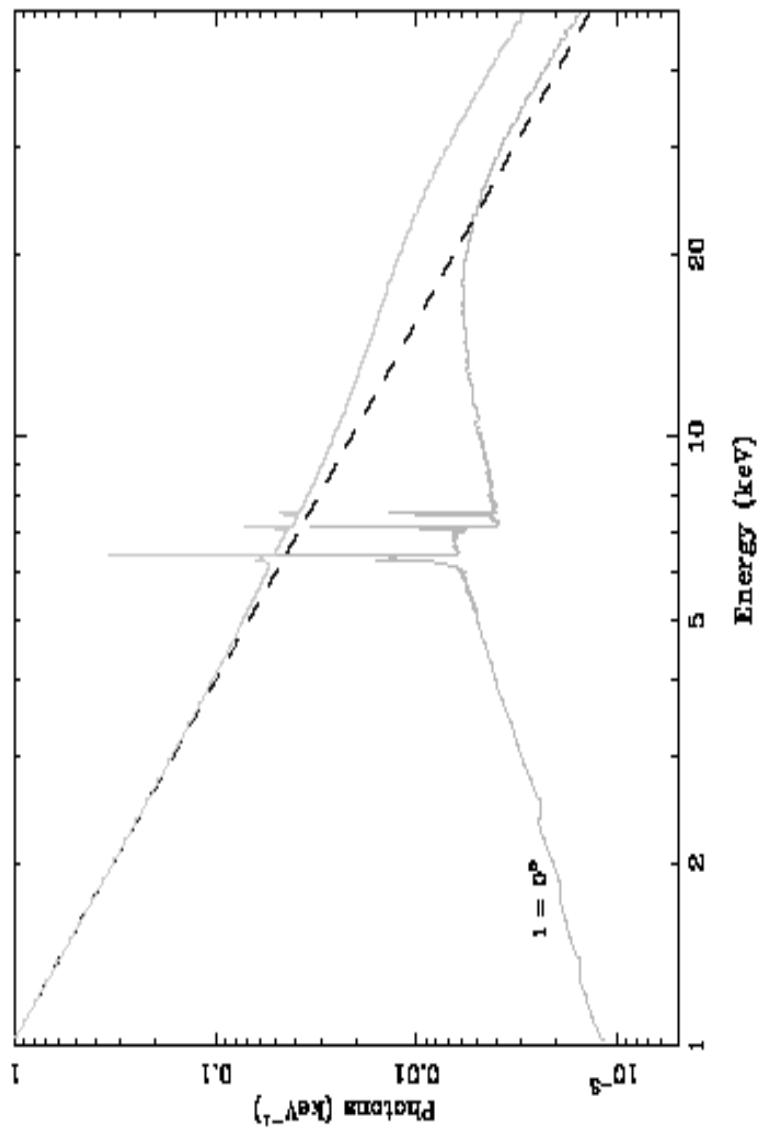


Fig. 7.1. A conceptual scheme for unification of Seyfert 1 and Seyfert 2 galaxies, not to scale. A highly opaque dusty torus surrounds the continuum source (black dot at center) and broad-line region (clouds near center). These cannot be viewed directly by an observer close to the torus midplane, although the narrow-line region and extended narrow-line region can be seen directly. This would lead the observer to classify the galaxy as a ‘Seyfert 2’. An observer closer to the torus axis would have an unobscured view of the nuclear regions and classify the same galaxy as a ‘Seyfert 1’. Figure courtesy of R. W. Pogge.

X-RAY EMISSION LINES



Iron K α Emission line (fluorescence) at 6.4 keV – also broad.
The line is accompanied by a Compton scattered continuum